GAMMA-RAY MONITORING OF A.G.N. AND GALACTIC BLACK HOLE CANDIDATES BY THE COMPTON GAMMA-RAY OBSERVATORY

R. T. Skelton, James C. Ling, Wm. A. Wheaton,
Jet Propulsion Laboratory, California Institute of Technology

Alan Harmon, G. J. Fishman, C. A. Meegan, William S. Paciesas[1],
Brad Rubin[2], R. B. Wilson,
Marshall Space Flight Center, NASA

Duane E. Gruber,
Center for Astrophysics and Space Science, UCSD

ABSTRACT

The Compton Gamma-Ray Observatory's Burst and Transient Source Experiment (BATSE) has a powerful capability to provide nearly uninterrupted monitoring in the 25 keV–10 MeV range of both A.G.N. and galactic black hole candidates such as Cygnus X-1, using the occultation of cosmic sources by the Earth. Since the Crab is detected by the BATSE Large Area Detectors with roughly 25σ significance in the 15–125 keV range in a single rise or set, a variation by a factor of two of a source having one-tenth the strength of Cygnus X-1 should be detectable within a day. Methods of modeling the background are discussed which will increase the accuracy, sensitivity, and reliability of the results beyond those obtainable from a linear background fit with a single rise or set discontinuity.

[1]University of Alabama at Huntsville
[2]USRA

The Burst and Transient Source Experiment (BATSE) aboard the Compton Gamma Ray Observatory (CGRO) offers a capability to provide almost uninterrupted monitoring of gamma-ray sources by Earth occultation. "Almost" means that one gets a measure of a source whenever it rises or sets in the 96-minute CGRO orbit. Those sources continuously above the horizon cannot be monitored, but the orbit precesses so that a source can spend only about two weeks continuously up before setting and again being subject to Earth occultation. BATSE consists of eight modules which are located octahedrally at the corners of the CGRO. Each module consists of a Large Area Detector (LAD), which is a NaI scintillator 50 cm in diameter and 1.25 cm thick, and a Spectroscopy Detector (SD), which is a 12.5 cm by 7.5 cm NaI scintillator. Data are accumulated in 2.048-second bins for each of 16 energy bands for the LADs; more sophisticated modes exist but have not been used to date in this investigation. BATSE is described in detail by Fishman *et al.* (1989).

The need for continuous monitoring of gamma-ray sources is illustrated by the fragmentary record of the premiere galactic candidate, Cygnus X-1, compiled by Ling *et al.* (1987a). It was noted to exhibit a two-week period of low flux below about 140 keV with a simultaneous high flux in the $\approx$ 1 MeV region in the form of a broad emission hump (Ling *et al.* 1983; Ling *et al.* 1987b). The hump can be interpreted as a Doppler-broadened and blue-shifted signature of electron-positron annihilation in an electron-positron plasma theoretically expected to result from photon-photon interactions near a luminous compact gamma-ray emitter (Liang 1979; Zdziarski 1980). Evidence, albeit at a $1.9\,\sigma$ level, has recently been noted (Ling and Wheaton 1989) of a narrow 511-keV line, present only during the time of the MeV hump, which could result from positrons being blown away by radiation pressure and annihilating in the primary star or its wind (Liang and Dermer 1988; Dermer and Liang 1988). For a positron-electron plasma, radiation pressure exceeds gravity by a factor of 20 in Cygnus X-1 (Kovner 1984). The Cygnus X-1 spectrum is similar to that observed for the galactic center (Lingenfelter and Ramaty 1983; Lingenfelter and Ramaty 1989; Riegler *et al.* 1981; Riegler *et al.* 1985). Variable MeV emission has been reported for NGC 4151, Cen A, and MCG 8-11-11 (Bazzano *et al.* 1989; Bassani and Dean 1983). Confirming the tentative results and establishing that the observed time variability and correlated spectral shifts constitute a pattern would allow better insight into the physics of compact objects.

The power of BATSE/Earth occultation is illustrated by Figure 1, which shows raw count rates for two orbits from the LAD most closely facing the Crab; the Crab becomes occulted at 1.9 hr and 3.4 hr and rises 0.5 hr later in each case, producing the prominent steps. A model consisting of a linear background (*vs* time) with a step discontinuity at the rise or set yields a statistical significance (combining all energy channels and LADs) of around $25\,\sigma$ for a single rise or set of the Crab with a fit window of ±262 sec. BATSE Mission Operations uses this simple model (which was quite effective at detecting the flaring of GX339−4 in June-July 1991, reported by Fishman *et al.* 1991) with a suitably selected time window to monitor the gamma-ray sky. The purpose of this paper is to report progress for an improved analysis which will allow monitoring to greater precision. Cutting measurement errors by, say, a factor of two would be of some value for a strong source like the Crab, but the greater motivation is to improve accuracy and sensitivity for weaker sources.

The linear-plus-step model is limited by the time window in which the background flux can be treated as linear. We have considered improvements along the lines of more polynomial terms, but the risk of introducing systematic errors outweighs the additional formal precision. A further fundamental problem is that polynomials are complete, and that the signal, a step function, can be represented by a sum of polynomials. Any complete mathematical model (Fourier series, etc.) shares the same shortcoming. Our approach will therefore be to model the sources of background with parameters that have a physical basis. In this manner we expect to increase the fit window substantially without introducing comparable systematic errors.

To illustrate the elements that must go into this model, we consider the general characteristics of the raw data. Figure 2 shows the first 12 hours of 17 April 1991 in the 1100–1800 keV band for each of the eight LADs. The count rates oscillate twice per orbit, and all LADs oscillate in phase. The dominant source of counts is cosmic-ray secondaries; the oscillations result from variations in the geomagnetic latitude. Variations from one LAD to another result primarily from Earth angles; at this relatively high energy, the Earth is bright from cosmic-ray secondaries compared to the diffuse cosmic background. Figure 3 shows the same time frame in the 24–32 keV band. The count rates oscillate once per orbit, with a narrow minimum compared to the broad maximum; oscillation amplitudes and phases differ. The dominant cause of variation is Earth blockage of the diffuse cosmic background. The narrow minimum corresponds to detector nadir. Two LADs whose numbers sum to seven face in opposite directions, and it is clear that count rates are 180° out of phase for such pairs.

Not shown are data from orbits wherein the CGRO passes through the South Atlantic Anomaly (SAA); the high voltage is switched off during actual passage, and activation decays are an obvious additional feature once HV is turned back on.

In light of this discussion, the dominant background contributors which must be modeled are diffuse cosmic gamma rays, cosmic-ray secondaries produced at the CGRO, cosmic-ray secondaries produced in the atmosphere, and activation. An enhanced model also needs to take account of the source confusion problem; combining set and rise data from the source into a single fit should alleviate this problem, because sources which are widely separated on the sky but which happen, for example, to set together will usually rise well separated.

Diffuse cosmic gamma rays refers to the aggregate output of sources too weak to catalogue individually, as well as truly diffuse sources. Since this contribution is approximately isotropic (with a nonisotropic galactic component), the primary modeling involved will be to define its spectral parameters and to account for blockage of it by the Earth.

Background due to prompt effects of cosmic rays is expected to be proportional to the SD upper level discriminators, based on experience with HEAO-3 (Mahoney et al. 1984). Work is in progress to extend the simple HEAO-3 model to make use of the 8 BATSE Spectroscopy Detector ULD rates to characterize the cosmic-ray environment and also the spectral dependence of the response.

In principle, background due to cosmic-ray secondaries produced from interactions with the Earth atmosphere presents the most formidable challenge. To be very precise, one must model the atmospheric response as a function of energies, each depending on the zenith angle and on the angle from the detector normal; the total LAD response would then obtained by integrating over the Earth disk. Again, experience with HEAO-3 leads us to believe that this extremely computationally intensive approach can be circumvented by suitably parametrizing the problem.

Activation occurs throughout the orbit, but is most significant during SAA passages. In principle, one simply integrates the activation rate vs time, weighting with the appropriate exponential for each radioactive species, and sums such exponential terms. In practice, there is difficulty in determining activation rates, which will differ among detectors, and the sum-of-exponentials problem has a notorious tendency to be ill-conditioned. Experience with HEAO-1 (Gruber et al. 1989) has shown how these problems can be overcome.

There exists a considerable body of experience in dealing with these matters, both by the authors and by others in the community, on spacecraft such as HEAO-1, HEAO-3, and the Solar Maximum Mission Gamma Ray Spectrometer. We believe that the challenges of increasing the fit window to improve the data analysis can be met and that considerable scientific value will result from the unprecedented continuous monitoring capability afforded by the CGRO and BATSE.

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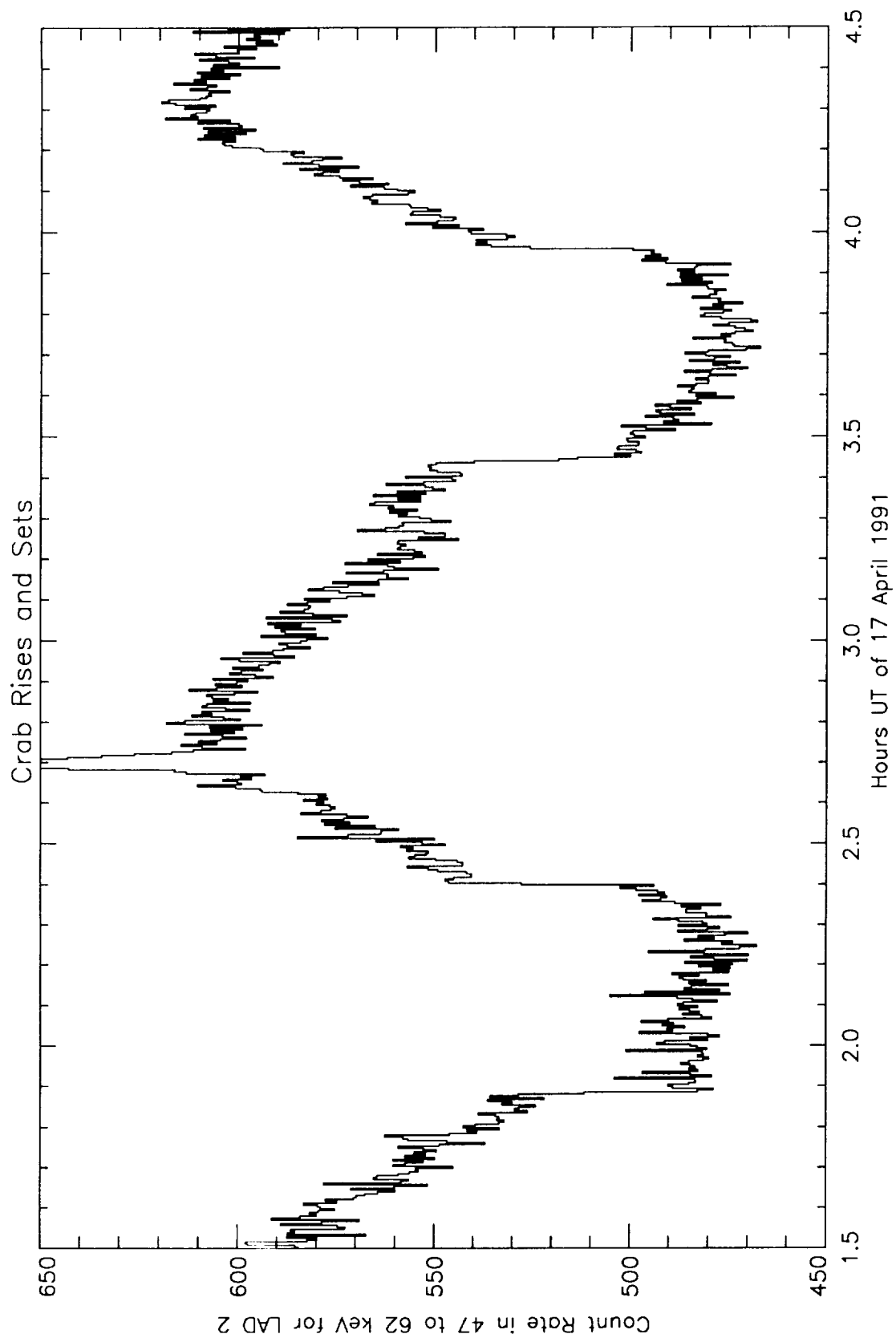Zdziarski, A. A. 1980, **Acta Astr.**, **30**, 371.

Figure 1. Raw data at 16.384-second time resolution showing step discontinuities at Crab sets (1.9 hr and 3.4 hr) and rises (2.4 hr and 3.9 hr)
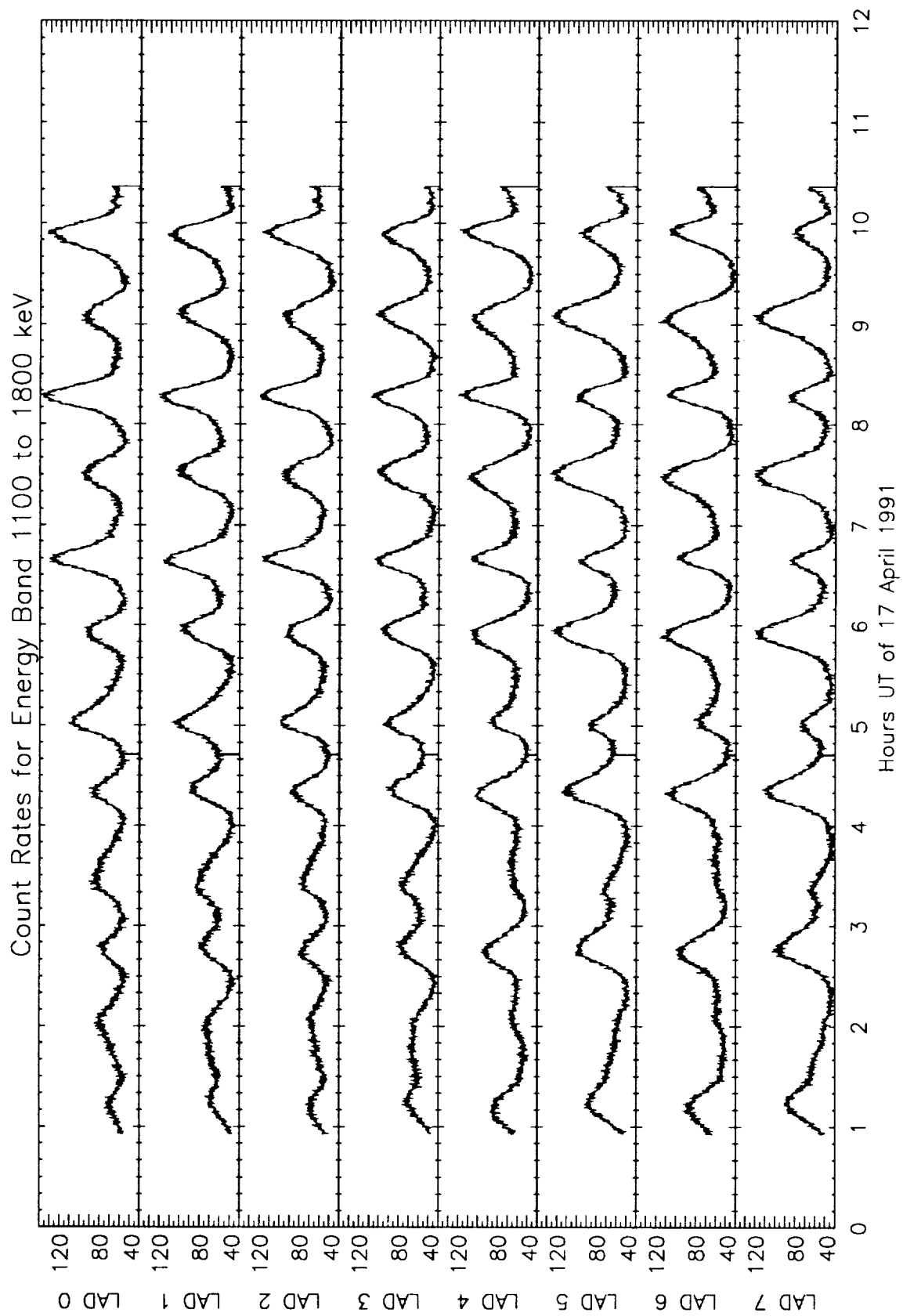
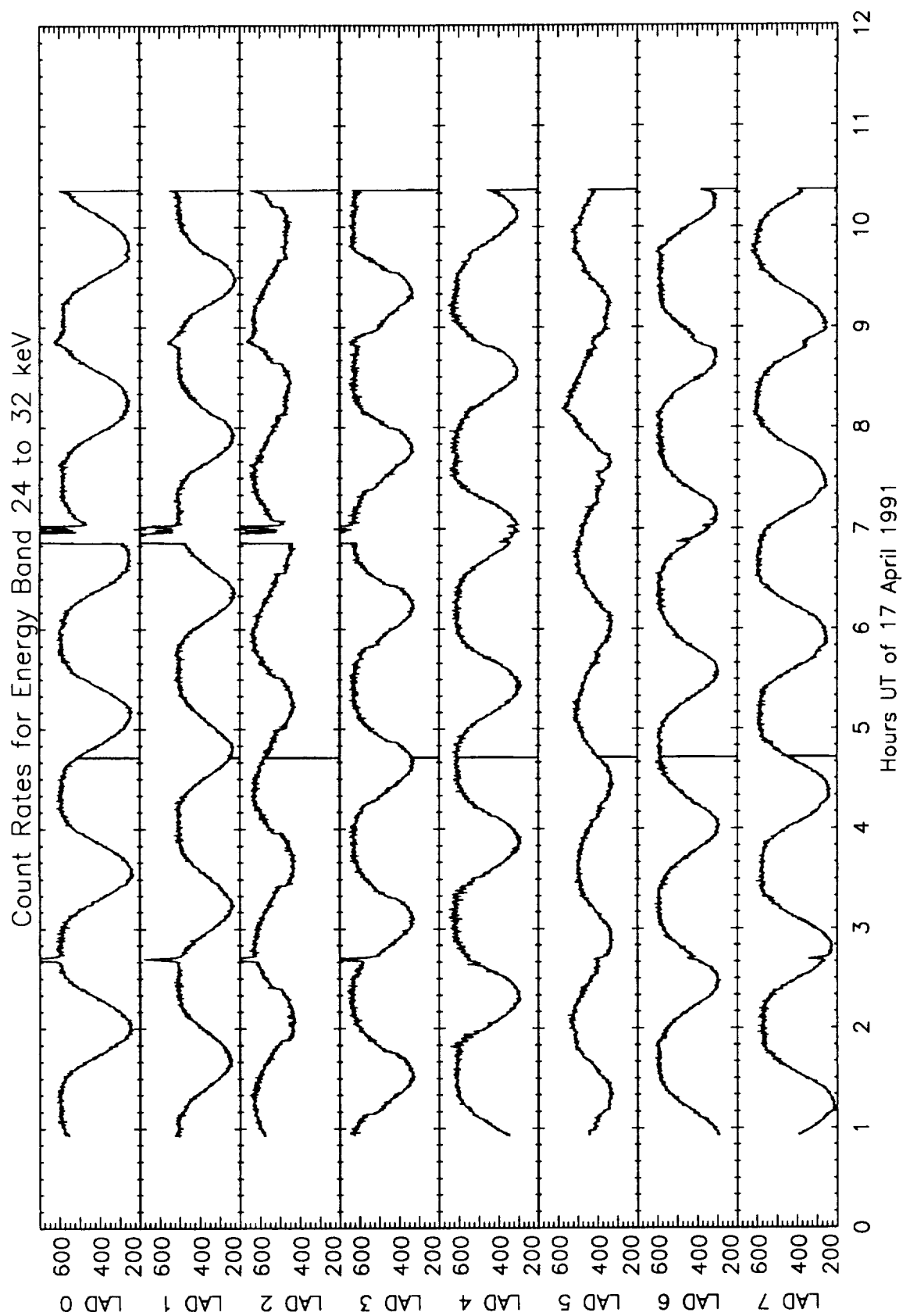Figure 2. Sample high-energy raw data from the 8 BATSE Large Area Detectors (LADs)

Figure 3. Sample low-energy raw data from the 8 BATSE Large Area Detectors (LADs)